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TRANSPORT OF COAL-TAR DERIVATIVES IN THE PRAIRIE DU CHIEN-JORDAN AQUIFER, ST. LOUIS PARK, MINNESOTA

A Project Proposal

by the

Minnesota District
U.S. Geological Survey

February 1981

INTRODUCTION

Operation of a coal-tar distillation and wood-preserving plant during 1918-72 in St. Louis Park, a suburb of Minneapolis, resulted in contamination of ground water. The severity of the contamination, and the efforts of local, State, and Federal agencies to define and resolve the technical, management, and legal issues involved, have made the matter highly visible. The Minnesota Pollution Control Agency and Region V of the EPA agree that coal-tar derivatives in ground water in St. Louis Park is the most significant single example of ground-water contamination identified to date within their jurisdictions.

In July 1978, the U.S. Geological Survey, in cooperation with the Minnesota Department of Health (MDH), began a 2-year project to develop a detailed understanding of the transport of coal-tar derivatives through the ground-water system in the St. Louis Park area. Information on multiaquifer wells in the area was provided to the MDH in February 1979. Hult and Schoenberg (1980) summarize data obtained during the first year of the study and present preliminary conceptual models of the mechanisms and pathways of contaminant transport. Hult (1981a) interprets these and additional data in greater detail and presents the results of preliminary analytical and computer modeling of transport in the Prairie du Chien-Jordan aquifer. Hult (1981b) evaluates the effect of multiaquifer wells on the spread of contaminants between aquifers.

As stated in the project proposal for the first 2-year project (December 1978, p. 2):

> "The problem is complex... The first two-year study (MN 79-061) will provide valuable insight into the problem and will aid decisions on probable continuation of the project for at least two more years. Development and application of a calibrated ground-water transport model to evaluate the possible effects of remedial actions proposed by State and local agencies will require extension of this project."

The new 2-year project now being proposed is in agreement with the timing and purpose of the project foreseen in 1978 and cited in the previous paragraph. The major effort will be to help resolve the contamination problem. Research by the Geological Survey of the St. Louis Park problem will have significant transfer value to similar problems elsewhere.

> "Because of intense local concern, considerable Federal interest, complexity of the problem, and difficulty of effective remedial action, it is anticipated that continued funding will be available. The approach to the problem must therefore balance the immediate needs of the cooperators with the longer-term requirements of a more definitive study." (1978 project proposal, p. 4).

THE PROBLEM

The problem of most immediate concern to the city and to State and Federal regulatory agencies is the presence of toxic organic compounds in water withdrawn from some municipal wells. When the first municipal well was drilled in 1932, the Prairie du Chien-Jordan aquifer contained water having a coal-tar taste at least 3,500 feet from the plant site. During 1978-80, use of five more St. Louis Park municipal wells completed in this aquifer was discontinued because the wells yielded water containing trace amounts of coal-tar compounds, including benzo(a)pyrene, a carcinogen.

Contaminants in the Prairie du Chien-Jordan aquifer have moved at least 2 miles northeast and southeast of the plant site. The direction and rate of contaminant movement changes with time because the bedrock ground-water flow system continually adjusts to hydraulic stresses caused by ground-water withdrawals and flow through wells that connect more than one aquifer. Contaminants can move rapidly through the Prairie du Chien-Jordan because the upper part of the aquifer is a carbonate rock having fracture and solution-channel permeability and low effective porosity. Consequently, the concentration and composition of contaminants in water pumped from individual industrial and municipal wells completed in the aquifer fluctuates with time.

The Prairie du Chien-Jordan aquifer is the region's major ground-water resource. About 75 percent of ground-water withdrawals in the St. Louis Park and Minneapolis-St. Paul metropolitan areas are from this aquifer. The aquifer is relatively well protected from near-surface sources of contamination. In the St. Louis Park area, it is 250 to 500 feet below land surface and is overlain by drift, two bedrock confining beds (Glenwood and basal St. Peter), and two bedrock aquifers (Platteville and St. Peter). Nonetheless, it is now contaminated. The project now being proposed will focus on the Prairie du Chien-Jordan aquifer because of its local and regional importance and the significance of the contamination to municipal water supplies.

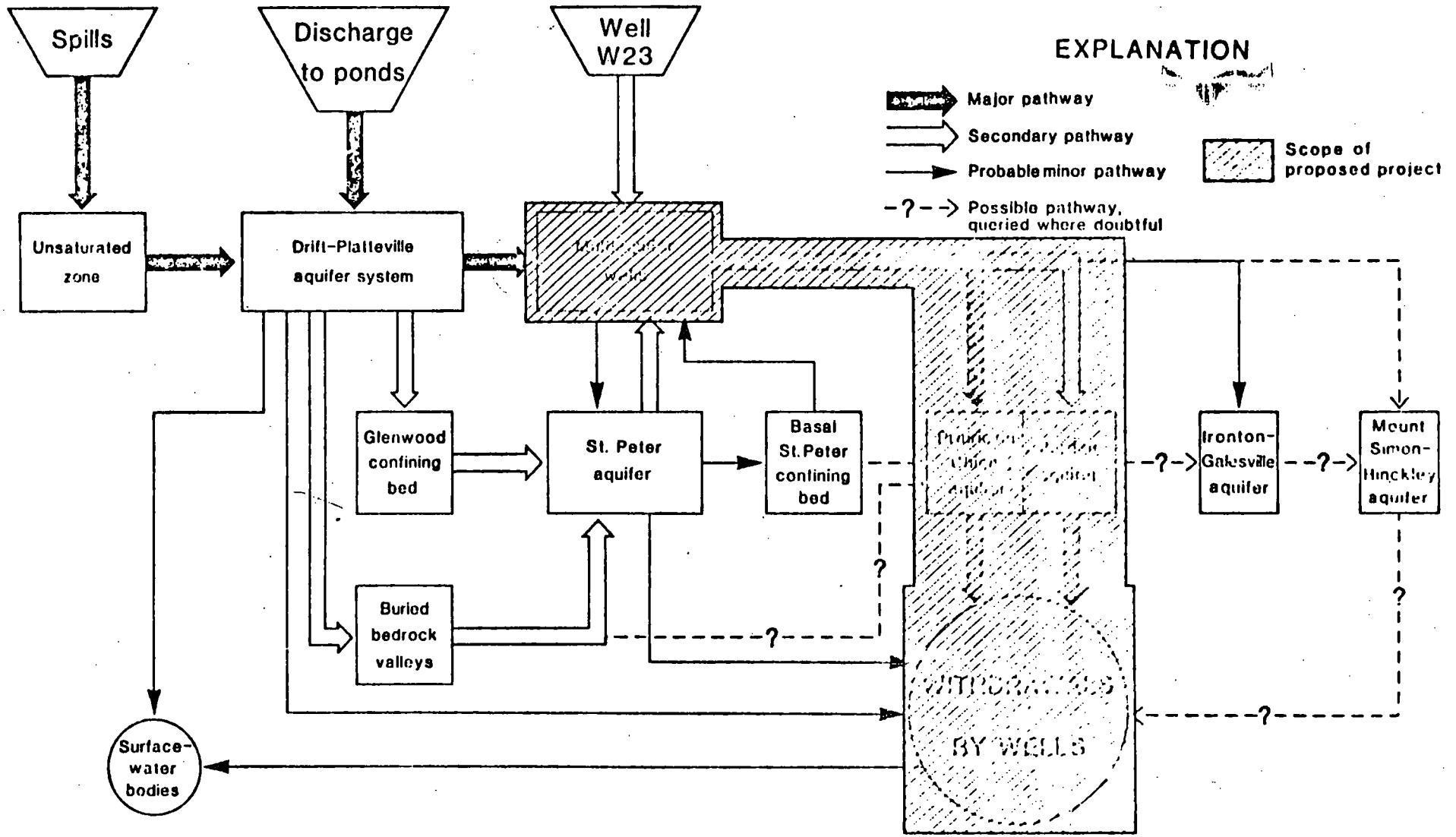


Figure 1.--Flow chart showing conceptual model of introduction and transport of coal-tar derivatives through the ground-water system, St. Louis Park area, Minnesota and scope of proposed project (modified from Hult, 1981a)

The greatest mass of contaminants is in the drift and uppermost bedrock aquifer (Platteville) near the site. Figure 1 shows the conceptual model of the introduction and transport of contaminants through the ground-water system. Coal-tar derivatives reached the water table by percolation through the unsaturated zone and through ponds that received surface runoff and process water from the plant (fig. 1). Parts of the drift contain an undissolved liquid mixture of many individual coal-tar compounds. In June 1980, a sample of this liquid from a monitoring well completed in the drift 50 feet below the water table contained 97,000 mg/L total organic carbon. The hydrocarbon fluid has moved vertically downward essentially perpendicular to the direction of ground-water flow because it is more dense than water. It is moving more slowly than the ground water because it is more viscous. Ground water entering the area of the plant site through the drift is contaminated by partial solution of the hydrocarbon fluids and by release of compounds sorbed on the drift materials. The contaminated water moves laterally to the east and southeast and downward into the Platteville aquifer. Water in the drift 4,000 feet from the site contains less than 10 mg/L dissolved organic carbon, but has a distinct "chemical" odor and contains a large proportion of coal-tar compounds of high solubility in water relative to compounds of low solubility. It seems that some organic compounds moving through the drift are being degraded by anerobic bacteria to other organic compounds and to methane. The USGS research group, with the assistance of the District, is continuing to investigate the rates of degradation, the compounds being degraded, and the nature of intermediate degradation products.

Contaminants entered the uppermost bedrock aquifer, the Platteville, directly from the drift and have moved at least 7,000 feet from the site. The contaminants reached deeper bedrock aquifers, primarily the Prairie du Chien-Jordan, through wells that hydraulically connect the aquifers (fig. 1). Coal-tar compounds have moved to a depth of at least 650 feet in the bore of a multiaquifer well 4,000 feet from the site. Locally, the contaminants have reached the St. Peter aquifer through the Glenwood confining bed and (or) through bedrock valleys where the confining bed has been removed by erosion (fig. 1). In addition, coal-tar has entered bedrock aquifers, possibly from a spill, directly through a well on the site that was drilled in 1917 to a depth of 909 feet (well W23; fig. 1).

OBJECTIVES

The goal of this and the previous study is to obtain a detailed understanding of the transport of coal-tar derivatives through the Prairie du Chien-Jordan aquifer in the St. Louis Park area. This understanding will be used to test management strategies suggested by the cooperators or their consultants and will have considerable transfer value to similar problems elsewhere.

The specific objectives are to:

1. Improve understanding of the distribution and movement of selected coal-tar derivatives in the Prairie du Chien-Jordan aquifer.
2. Provide for consultation between the USGS, EPA, MDH, MPCA, the city of St. Louis Park, and the private consultants to MDH.

3. Provide for continued geophysical logging and evaluation of multiaquifer wells as they are located in the field.
4. Obtain additional information on the physical and chemical characteristics of the source volume of contaminants in the drift and in well W23.
5. Preserve continuity in the collection of time-series, water-level, and pumpage data from all aquifers.
6. Provide continuing support for related, but separately funded, research by the Geological Survey, such as the study of biodegradation of coal-tar derivatives.

SCOPE

A major emphasis in the proposed project is development of a method for evaluating the effectiveness of measures proposed to minimize both the concentration of coal-tar derivatives in municipal wells and the continued spread of contaminants in the Prairie du Chien-Jordan aquifer. Hult (1981a) has shown that manipulation of withdrawals from industrial and municipal wells, in conjunction with a continued effort to locate, evaluate, and seal multiaquifer wells that permit contaminated water to flow into the aquifer, may be effective in minimizing the concentration of contaminants reaching municipal wells. Preliminary solute-transport computer models have proven to be useful tools in evaluating the problem. The proposed project focuses on refining these tools to better reflect hydrogeologic conditions and on using them to evaluate the hydrologic effects of future management.

Multiaquifer wells are the major pathways identified, to date, of contaminant transport to the Prairie du Chien-Jordan aquifer (Hult, 1981a; 1981b). Continuing evaluation of multiaquifer wells, in conjunction with the well-abandonment program of MDH, is within the scope of the proposed project. Reconstruction of multiaquifer wells as monitoring wells would be highly desirable but would require additional funding.

Evaluation of other pathways of contaminant transport to the aquifer, such as those shown in figure 1, will depend mostly on previously collected data. Coal tar entered the Prairie du Chien-Jordan aquifer through a deep well on the site (well W23; "Hinckley well on the site"). The coal tar in and around the well may be a continuing source of contaminants to the aquifer (Hult, 1978; 1981a; 1981b; Hult and Schoenberg, 1980). Tar and water samples from the well will be collected and analyzed for the proposed project. Additional steps needed to evaluate this source have been suggested to the MDH and would require additional funding. Contaminants may also be entering the Prairie du Chien-Jordan from the overlying St. Peter aquifer (fig. 1). The mass of contaminants entering the aquifer through this path seems to be small compared with entering through multiaquifer wells (Hult 1981a). Additional monitoring wells would be needed to further test this hypothesis and would require additional funding.

Management strategies aimed at minimizing the impact of the contaminants are summarized in table 1. Each of the three user alternatives have been implemented or are being evaluated by the city of St. Louis Park. The quality of water withdrawn from municipal wells is being monitored by the city and the MDH. Pilot studies by the city and their consultants have shown that organic contaminants can be partly removed by treatment with activated carbon. The city has increased withdrawals from deeper wells in the Mount Simon-Hinckley aquifer and is evaluating the cost and desirability of deepening wells, drilling new deeper wells, and (or) obtaining water from Minneapolis.

Table 1.--Summary of management strategies to minimize the impact of ground-water contaminants (modified from Hult, 1981a)

1. USER ALTERNATIVES

   a. Monitor the quality of water at the well head. If quality is unacceptable,

   b. Treat, or

   c. Develop alternative supplies.

2. AQUIFER MANAGEMENT

   a. Prevent or reduce movement of contaminants into the aquifers. For example, locate and seal multiaquifer wells that permit contaminated water to flow into the Prairie du Chien-Jordan aquifer.

   b. Control the movement of contaminants within the aquifers, so that the concentration of contaminants at each withdrawal well does not exceed acceptable limits. In the Prairie du Chien-Jordan, this might be accomplished by manipulating pumpage from municipal and industrial wells and by pumping wells installed for controlling hydraulic gradients.

3. SOURCE MANAGEMENT

   a. Intercept contamination leaving the source with withdrawal wells, treat (if necessary), and reinject or discharge.

   b. Immobilize the contaminants in the source either with hydraulic or physical barriers or by chemically reducing contaminant solubility.

   c. Convert contaminant compounds in the source to other compounds that are less toxic by encouraging insitu degradation by anerobic bacteria or by providing oxygen for degradation by aerobic bacteria.

   d. Remove (partly) the source by excavation and pumpout wells.

The proposed project will focus on using a solute-transport model to evaluate the hydrologic effects of the aquifer-management strategies for the Prairie du Chien-Jordan indicated in table 1. The MDH began a program of well abandonment in February 1979, based on information provided by the USGS. This program has been effective in reducing the amount of contaminants entering the Prairie du Chien-Jordan aquifer. Manipulating pumpage from wells may be effective in reducing the contaminant concentration at any given well and in preventing further spread of contaminants. Figure 2 shows changes in the concentration of some coal-tar compounds in water from St. Louis Park municipal well 4 and pumpage from municipal well 6. Well 4 was pumped only for obtaining samples. Both wells are completed in the Prairie du Chien-Jordan aquifer; no other nearby wells were known to have been pumping during the period indicated. The data from wells 4 and 6 support the tentative conclusion that manipulating pumpage may be effective in reducing contaminant concentrations at individual withdrawal wells. However, additional time-series data on contaminant concentration, pumpage, and water levels are needed to test whether the correlation between pumpage and chemical concentration is coincidental or whether there is a causal relationship.

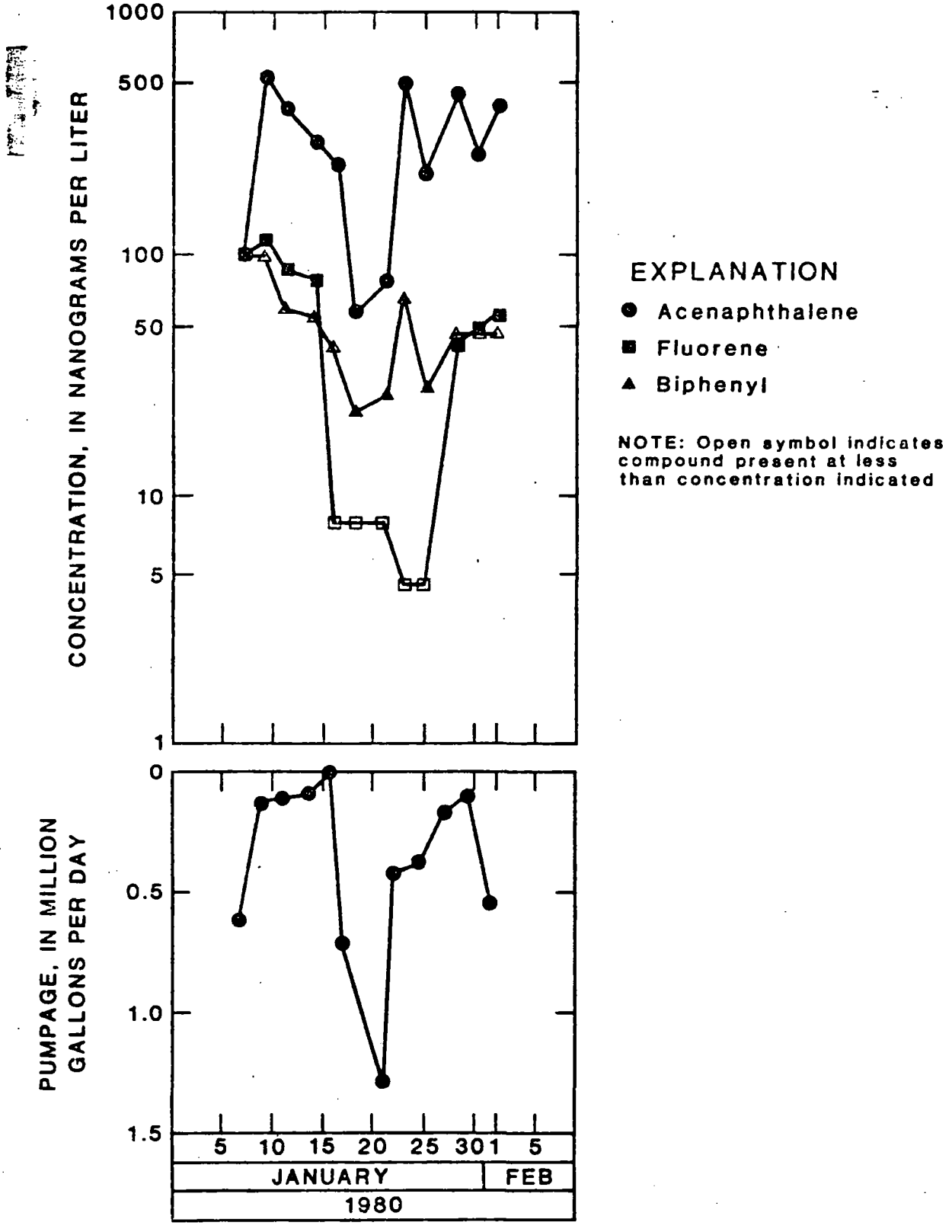


Figure 2.--Changes in water quality in St. Louis Park Municipal Well 4 and pumpage from Well 6, January 1980. Both wells are completed in the Prairie du Chien-Jordan aquifer (from Hult, 1981a)

Continued detailed evaluation of the contaminant source in the drift and Platteville aquifer and of movement of contaminants through the St. Peter, Ironton-Galesville, and Mount Simon-Hinckley aquifers is beyond the scope of the proposed project. However, some additional work on aspects of the problem have been incorporated into the proposed project, which will aid in designing and evaluating the source-management strategies shown in table 1. Results of ongoing basic research by the Geological Survey will be directly applicable to the St. Louis Park problem, but some outstanding questions are sitespecific and will require additional fieldwork. The scope of the proposed project could be expanded to include additional work if funds become available. The relationship between past projects, the proposed project, and possible future projects is shown in table 2.

Table 2.--Relationship of proposed project to past and possible future projects

USGS project	Dates	Principal objectives	Related activities by other agencies	USGS publications
Project MN-79-061	July 1978-June 1979	Develop an understanding of the transport of coal-tar derivatives through aquifers in the St. Louis Park area.	Well abandonment program by MDH	Hult and Schoenberg, 1980
	July 1979-Sept. 1980			Hult, 1981a; 1981b
Proposed project	Oct. 1980-Sept. 1982	Develop an improved understanding of contaminant distribution and transport in the Prairie du Chien-Jordan aquifer.	Design of proposed remedial action by consultants to MDH	1982
Possible future projects	Oct. 1981-Sept. 1982	Continue collection of time-series data in all aquifers. If additional funds become available, refine understanding of transport in the drift, Platteville, St. Peter, Ironton-Galesville, and Mount Simon-Hinckley aquifers, as needed to evaluate proposed remedial measures.	Implementation of remedial actions by State and local agencies	
	Oct. 1982-Sept. 1983	Attempt calibration of transport models based on 4 years of time-series chemical data and response of the ground-water system to remedial actions. Design a long-term strategy to monitor and evaluuate the effectiveness of remedial measures.		

APPROACH

The principal activities needed to meet the objectives are (1) a mass sampling of wells in the Prairie du Chien-Jordan aquifer to determine the areal extent of measureable contamination, (2) refinement and maintenance of the network used to monitor water levels, water quality, and pumpage, (3) additional coring, sampling, and chemical analyses to better define the composition and physical characteristics of the contaminant sources in the drift and well W23, (4) continued work on identifying, locating, testing, and sealing or reconstructing multiaquifer wells; this work will be coordinated with the MDH and (5) refinement of transport models of the Prairie du Chien-Jordan aquifer to reflect hydrogeologic boundaries and hydraulic and chemical stresses. As funding, time, and the availability of wells permit, attempts will be made to obtain additional time-series data on water quality in the Prairie du Chien-Jordan and to continue monitoring water quality in other aquifers.

The Regional Water-Quality Specialist will be consulted to develop a quality-assurance program. This is needed to ensure the validity of chemical analyses from the various laboratories involved. Continued support will be available from the Geological Survey laboratories in developing the quality-assurance program and in chemical characterization of the contaminants. A complete description of the quality-assurance program will be developed as part of the proposed project.

Mass Sampling of Prairie du Chien-Jordan Aquifer

Mass sampling of water from wells in the Prairie du Chien-Jordan aquifer is needed to obtain more complete information on the distribution of individual organic and inorganic constituents within the aquifer at a single time. No additional wells will be installed for this sampling effort. Many wells in the area are used for air conditioning and irrigation and may not be available for sampling during the winter. An attempt will be made to coordinate this sampling with the ongoing monitoring by MDH. Specifically, MDH could help by making arrangements for sampling of wells that are not usually available. It would also be highly desirable for MDH to analyze the concentration of PAH compounds by HPLC in samples taken at the same time as those collected by the Survey for analysis by an EPA contractor. Because MDH intends to continue monitoring, this approach will require no additional laboratory work by MDH. It will, however, help in the evaluation of the compatibility and reproducibility of analytical results from the various laboratories.

Tasks:
1. Compile available information on water quality and wells.
2. Identify areas where additional wells are needed.
3. Compile list of candidate wells for sampling.
4. Field locate new wells and make necessary arrangements.
5. Sample approximately 40 wells within 2- to 4-week period.

Refinement and Maintenance of Monitoring Network

Water quality, water levels, and(or) pumpage from about 300 wells in the St. Louis Park area were measured as part of the previous project. This network will be reevaluated, modified, and maintained as necessary to best meet the data needs of the proposed project and future activities.

About four additional recorders will be installed to monitor pumpage and water levels in the Prairie du Chien-Jordan aquifer. The frequency of measurement will be reduced at most wells in the drift and Platteville aquifers. Attempts will continue to locate additional wells in areas where data are sparse.

Physical and Chemical Characterization of the Drift and Platteville Aquifers and Contaminants in Well 23

Cores will be obtained from at least two additional test holes in the most highly contaminated volume of drift and from the coal tar in Well 23. These samples, some previously collected cores, and fluid pumped from selected wells will be analyzed for individual organic compounds. The samples will be analyzed by an EPA contractor and by the Geological Survey to obtain a complete chemical characterization of coal-tar derivatives in the source volume of contaminants. Fluid samples collected from a mass-sampling program will be analyzed by MDH and the EPA contractor for selected compounds to aid in delimiting the areal extent and severity of contamination in the aquifers. Continued work on the chemical and biological fate of the organic contaminants in the drift and Platteville aquifers will be coordinated with the Survey research group.

Aquifer tests in the drift and Platteville aquifers are needed to better evaluate strategies. Pumping tests will be made if MPCA can obtain necessary permits (if any) for discharge of contaminated water. Additional testing may include slug-testing of piezometers and laboratory analyses of cores for porosity and hydraulic conductivity.

Evaluation of Multiaquifer Wells

As additional wells are located in the field, the Geological Survey will log the wells geophysically and measure water levels and vertical flow within the well bore (if any). The MDH will provide for removal of obstructions in the well bore (if any), collect and analyze water samples, log with downhole television camera, and permanently seal or reconstruct as monitoring wells, if needed and as funding permits.

Model Development

The purpose of a ground-water solute-transport model is to (1) provide a framework for quantitative accounting of the major processes in and properties of the ground-water system that govern the transport of contaminants and (2) provide a tool that can be used in evaluating the effectiveness of remedial actions for reducing contamination in the Prairie du Chien-Jordan aquifer.

Tasks:

1. Expand and refine present two-dimensional transport model (Konikow and Broedehoeft code) to better reflect actual conditions. Test parameter sensitivities.
2. Using SWIP, incorporate separate layers for Prairie du Chien and Jordan and realistic boundary conditions. Attempt calibration by matching head changes (steady-state and transient).

2a. If necessary to reduce computer costs, construct and use three-dimensional flow model (Trescott code) to evaluate flow problem. Transfer refinements to SWIP and retest.

3. Using SWIP, add simplified history of contaminant introduction to evaluate transport rates and directions, parameter sensitivities, and uncertainties that may be caused by unlocated multiaquifer wells.
4. Using SWIP and the measured distribution of contaminants, evaluate effect of manipulating pumpage, including municipal wells, industrial wells, and hypothetical gradient-control wells.
5. Using SWIP, and as time and time-series data permit, attempt calibration of transient transport of selected contaminants.

Model data needs and source of information

1. Aquifer and confining bed geometry - from Hult and Schoenberg, 1980; Guswa, 1981.
2. Aquifer and confining bed hydraulic properties - from previous pumping and laboratory tests in St. Louis Park and elsewhere in the Twin Cities basin - Guswa, 1981; and ATES project.
3. Hydrogeologic boundaries - from Guswa, 1981 (Twin Cities project).
4. Time-series data on hydraulic head - from Hult and Schoenberg, 1980; Guswa, 1981, and from monitoring network refined and operated for the current project.
5. Adsorption isotherms - from batch experiments to be conducted by the University of Minnesota for phenol, naphthalene, and acenaphthene.
6. Time-series data on ground-water withdrawals - compiled for previous project (061) and from monitoring network refined and operated for current project.
7. Hydraulic effect of multiaquifer wells - from Hult, 1981a; 1981b; and from measurements made for the current project.
8. Chemical effects of multiaquifer wells - from Hult and Schoenberg, 1980; Hult, 1981a; 1981b; and from measurements made for the current project.
9. Present distribution of selected contaminant compounds - from Hult, 1981a, and from chemical mass measurements made for the current project.
10. Time-series data on concentration of selected contaminant compounds - from Hult, 1981a. Some additional measurements may be made for the current project.

TIME SCHEDULE AND REPORT PLANS

The project will take 2 years to complete. Fieldwork (other than network maintenance), model development, and report preparation will be completed in FY 81. The report will be submitted to the Region by April 1, 1982. Because of the need for speedy publication, the report will be published in the WRI series. At some later time, however, the report could be considered for WSP publication.

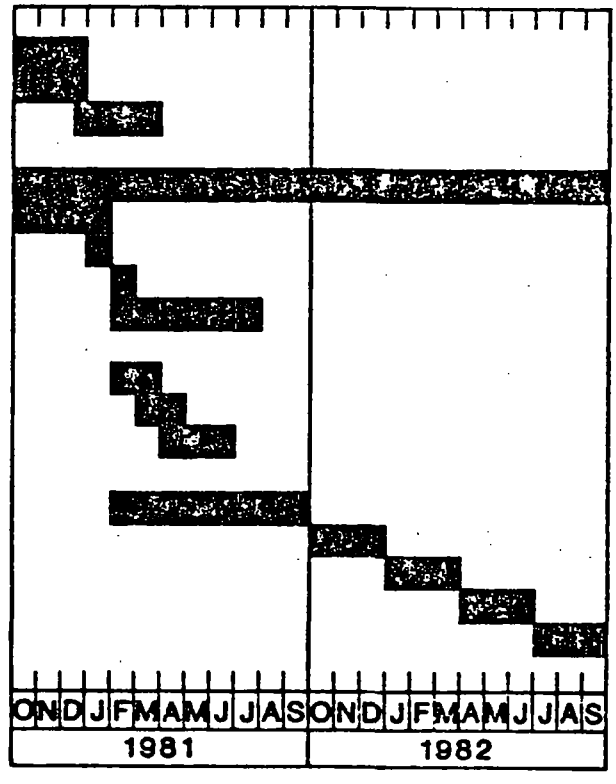
SUMMARY WORK PLAN

Project Proposal and Plan
Previous Reports to District
Design Quality Assurance Program

Maintain Hydrologic Data Network
Initial Fieldwork
Initial Sampling
Mass Sampling
Additional Fieldwork

Refine Transport Model
SWIP Model Functional
SWIP Model Well-posed

Report Preparation
District Review
Colleague Review
Region Review and Headquarters
Drafting and Printing



COST SCHEDULE

The costs for this project (Federal FY 81 and 82) will be shared by the city of St. Louis Park, MDH, MPCA, EPA and the USGS. The MDH will collect and analyze samples from municipal wells, provide downhole television camera surveys, and prepare selected wells for geophysical logging (through the well-abandonment program) in the amount of $36,000 in lieu of funds that will be matched by the Survey. The city of St. Louis Park will assist in monitoring pumpage, water levels, and water quality in municipal wells, and will provide landscaping of monitoring-well sites in the amount of $10,000 in lieu of funds that will be matched by the Survey. Proposed funding and expenditures are as follows.

St. Louis Park Proposed Funding for FY 81

	Cash	Services	USGS match	WOTSC[1]	DOTSC[2]	Net cash
EPA	$50,000	$ ---	$ ---	$ 7,250	$12,750	$30,000
SLP	5,000	10,000	15,000	2,700	5,100	12,200
MPCA	14,000[3]	---	14,000	2,520	7,140	18,340
MDH	5,000	36,000	41,000	7,380	11,730	26,890
Total	74,000	46,000	70,000	19,850	36,720	87,430

[1] EPA - 14.5 percent; all others at 9 percent.
[2] 25.5 percent of all cash and matching; 0 percent on direct services.
[3] Funds may come from either MPCA or MDH.

Itemized expenditures for FY 1981

Salaries	$ 48,430
Travel	3,000
Supplies	2,500
Equipment	5,000
Vehicles	2,800
Computer	10,700
Laboratory	5,000
Drilling and physical analyses of cores	7,000
Analytical services (University of Minnesota)	3,000
District support	36,720
Headquarters support	19,850
Direct services	46,000
Total	190,000

Proposed Funding for FY 82--Report processing and publication

Salaries	$ 19,000
Printing and reproduction	2,500
District support	8,500
Headquarters support	3,000
Total	$ 33,000

PERSONNEL REQUIREMENTS AND AVAILABILITY

District personnel needed for the project are as follows:

	FY 81	FY 82
Hydrologist GS-11	full time	1/2 time
Hydrologist GS-11	1/5 time	---
Hydrologist GS-7	1/4 time	---
Hydrologic Technician	3/4 time	1/4 time

These personnel are presently available in the District.

The assistance of the Regional Water-Quality Specialist will be requested to help develop a quality-assurance program in coordination with the Central Laboratory and the research group. Ongoing research on biotransformation will probably continue. District assistance in the use of the SWIP code is available, but additional consultants may be required.

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